THE GENUS *WOLFFIA* (LEMNACEAE) IN CALIFORNIA

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ABSTRACT

Three species of *Wolffia* occur in California: *W. columbiana, W. globosa* and *W. borealis*. Because of their small size and relatively few critical morphological characteristics they have often been misidentified, and confusion has resulted from several different published epithets for each taxon. They are distributed throughout the state in marshes and ponds, often in disjunct clonal populations. All three species have extensive geographical distributions outside the state.

INTRODUCTION

The genus *Wolffia* Horkel (Lemnaceae) includes the smallest and structurally simplest of all angiosperms. Individuals of these free-floating, rootless plants are barely visible without magnification. They occur in dense, homogeneous populations forming a greenish layer at the surface of quiet streams and ponds (Armstrong 1982), and are commonly associated with *Lemna, Spirodela, Wolffiella* and *Azolla*. Of the nine species of *Wolffia* (Landolt 1980a), three appear to occur in California. The primary objective of this paper is to clarify exactly which species occur in California and to elucidate their distribution within the state.

Several taxonomic studies of the Lemnaceae have been published during the past three decades, and there is considerable disagreement among California and other authors over which species occur in California (Mason 1957; Landolt 1957, 1980a, 1980b; Daubs 1965; den Hartog and van der Plas 1970; Clark 1979). The occurrence of *Wolffia columbiana* Karst. is agreed upon by all the authorities cited above. *Wolffia globosa* (Roxb.) Hartog & Plas was listed as *W. cylindracea* Hegelm. by Galen Smith in Mason (1957) and *W. punctata* Griseb. by Landolt (1957). Daubs (1965) considered *W. cylindracea* synonymous with *W. arrhiza* (L.) Horkel ex Wimmer, a European species that does not occur in North America. Probably the greatest confusion concerns the correct usage of *W. punctata*. According to Landolt (1980a), the original *W. punctata* described by Grisebach in 1864, and *W. papulifera* Thompson described in 1898, are synonymous with *W. brasiliensis* Weddell, described earlier in 1849. *Wolffia brasiliensis* occurs throughout the southeastern

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United States and in Central and South America, but does not occur in California. Vegetative fronds of this species are distinguished by a prominent central papule on the dorsal surface. The *W. punctata* referred to by most American authorities is actually *W. borealis* (Engelm.) Landolt, a North American species closely related to *W. brasiliensis*. It was originally listed as *W. brasiliensis* var. *borealis* Engelm. ex Hegelmaier (1868) and later changed to *W. borealis* (Landolt and Wildi 1977).

Some confusion between *Wolffia brasiliensis* and its complex of synonyms may be due to early publications of Weddell (1849), Hegelmaier (1868) and Thompson (1898), which do not show the prominent central papule. According to Landolt (pers. comm., 29 Dec 1983) the type collection of *W. brasiliensis* from Mato Grosso, Brazil contains flowering and fruiting fronds that do not show a papule. The few vegetative fronds in the collection also do not show a very prominent papule. The other specimens Hegelmaier saw for his monograph, in addition to the type collection, originated from the northern United States and belong to *W. borealis*. Without the dorsal papule, fronds of *W. brasiliensis* easily can be mistaken for *W. borealis* or one of its synonyms, and these errors have been perpetuated in the literature for more than a century.

Methods and Materials

Herbarium specimens of *Wolffia* species in California were compared and previous collection sites were revisited during the summer and fall of 1980–83. New collections were made, including several range extensions. Since the fronds become barely recognizable after pressing, photomicrographs of living plants were included on herbarium sheets. For positive identification, living samples of all collections were compared with clonal cultures from the laboratory of Dr. E. Landolt, Geobotanical Institute, Zurich.

Results and Discussion

Species of *Wolffia* are often difficult to separate in a taxonomic key. They have relatively few critical morphological characteristics and are rarely found with flowers or fruits. Often there is overlap in size and shape of fronds. Ideally, it is best to compare species floating in a shallow container, preferably through a dissecting microscope (Figs. 1, 2). The California species of *Wolffia* may be identified by use of the following key:

A. Fronds ovoid to ellipsoid with flattened dorsal surface, apex ± pointed (acute) and slightly upturned, floating with entire dorsal surface above water; greatest width of frond near water surface; brownish pigment cells present (visible only on dead fronds ..... 1. *W. borealis* (Engelm.) Landolt

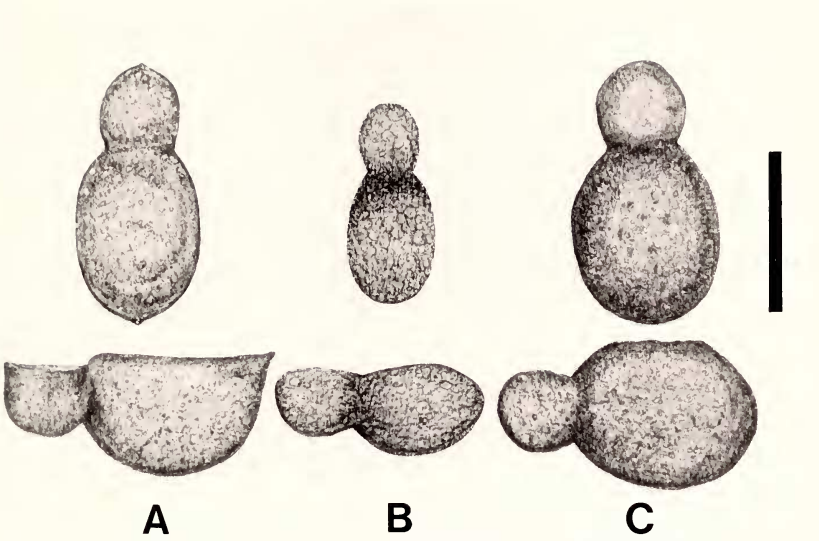

FIG. 1. Dorsal and lateral views of *Wolffia* species. A. *W. borealis.* B. *W. globosa.* C. *W. columbiana.* Scale bar is 1 mm.

AA. Fronds ovoid or globoid (often ellipsoid or cylindrical in *W. globosa*), apex of fronds rounded, floating with only the central portion of dorsal surface above water; submerged body of frond wider than dorsal surface; brown pigment cells lacking.

B. Fronds 0.8 to 1.3 mm long; dorsal surface rounded or slightly flattened, minutely roughened by enlarged cells ..... 2. *W. columbiana* Karst.

BB. Fronds 0.4 to 0.9 mm long; dorsal surface flattened and minutely roughened by a few enlarged cells .... 3. *W. globosa* (Roxb.) Hartog & Plas

When fronds of all three species are viewed from above (Fig. 1), *Wolffia borealis* appears darker green with a pointed apex. Fronds of *W. columbiana* and *W. globosa* are distinctly light, transparent green with a rounded apex. Fronds of *W. globosa,* rivaled in minuteness only by the Australian species *W. angusta* Landolt, are smaller and more cylindrical (narrow) than in *W. columbiana.* With substage lighting, the densely pigmented fronds of *W. borealis* appear black. However, in photographs with substage lighting and lighting from above, the transparent fronds of *W. columbiana* and *W. globosa* often appear darker than those of *W. borealis* (Fig. 2).

With the exception of *W. borealis,* which has brownish pigment cells, dried, pressed specimens are often difficult to identify. Ideally, herbarium sheets should include detailed notes on shape and size

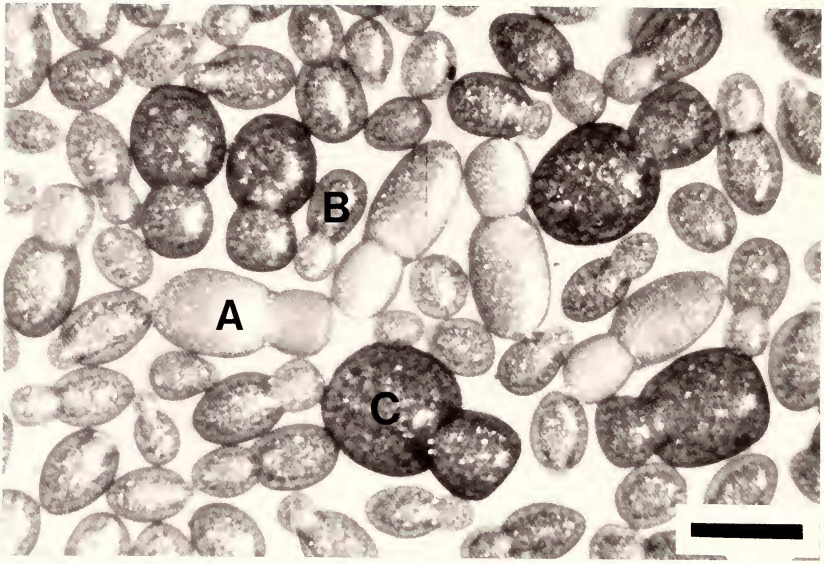

FIG. 2. Dorsal view of *Wolffia* species showing relative size and shape of fronds. A. *W. borealis*. B. *W. globosa*. C. *W. columbiana*. Scale bar is 1 mm.

of fronds, and preferably photomicrographs or references to duplicate specimens preserved in fluid. Plants may remain alive in aerated containers for several days, but should be placed in a preservative for long-term storage. Fronds retain their original shapes in FAA or ethanol. Formalin is not advisable because the plants become very fragile (van der Plas 1971).

DISTRIBUTION

Stations for *Wolffia* known to the authors in California are shown in Fig. 3. Because of their small size, generally 0.6 to 1.2 mm long, they are easily overlooked. Diligent field work could probably fill many gaps in the distribution patterns of all three species. Collections of *Wolffia* in California are cited by Mason (1957), Landolt (1957), Daubs (1965), Landolt and Urbanska-Worytkiewicz (1980) and Armstrong (1981a, 1981b). In addition, Urbanska-Worytkiewicz (1980) reports chromosome numbers for all species, including several polyploid populations in California.

Wolffia columbiana occurs in San Diego County (Lake Hodges and San Dieguito River) and in San Luis Obispo County (Oso Flaco Lake and perhaps other lakes and ponds of the Nipomo Mesa area, and near Oceano). It also occurs sparingly in Fresno County (sloughs along the San Joaquin River) and in Stanislaus County (west of Modesto).

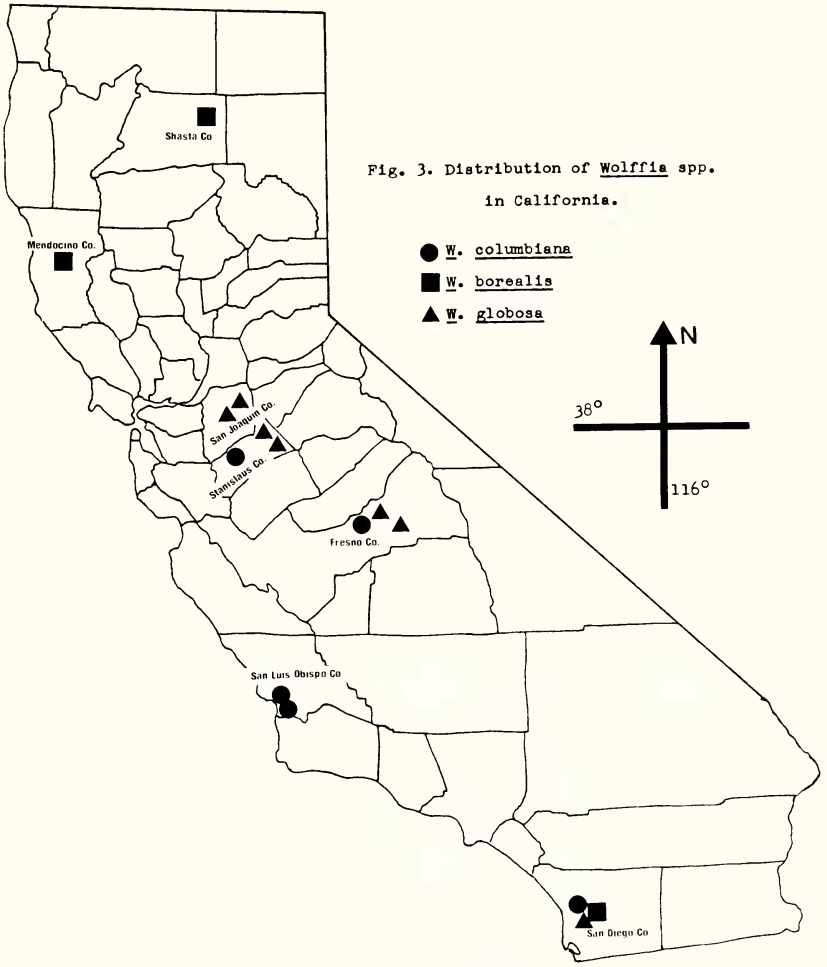

FIG. 3. Map showing the distribution of *Wolffia* species in California.

California: FRESNO CO.: San Joaquin River, *Nobs and Smith 992a* (ARIZ, MO, WIS). SAN DIEGO CO.: pond s. of Lake Hodges, *Armstrong 1195* (RSA, SD); San Dieguito River, *Armstrong 1124, 1167, 1176, 1183* (RSA, SD). SAN LUIS OBISPO CO.: Dune Lake, *Mason 12864* (MICH, RM, UC); near Oceano, *Nobs and Smith 676* (UC); Oso Flaco Lake, *Armstrong 1133* (RSA, SD), *Landolt 6859, 8143* (ZT), *Piehl 63781* (RSA). STANISLAUS CO.: w. of Modesto, *Smith 2660* (UC).

Wolffia globosa is apparently confined to ditches and ponds of the extreme northern and central San Joaquin Valley, and in sloughs along rivers draining the Sierra Nevada. It occurs in northeastern

San Joaquin County (southwest of Ione), Stanislaus County (Knights Ferry and La Grange), and Fresno County (northwest of Clovis and near Minkler). It was recently collected in a small pond (south of Lake Hodges) in San Diego County (see Noteworthy Collections, p. 191).

California: FRESNO CO.: Minkler, *Landolt* (ZT); San Joaquin River, *Armstrong 1135* (RSA, SD), *Landolt 6724, 8152* (ZT), *Nobs and Smith 992a* (ARIZ, MO). SAN DIEGO CO.: s. of Lake Hodges, *Armstrong 1196, 1197* (RSA, SD). SAN JOAQUIN CO.: sw. of Ione, *Russell and Swader s.n.* (RSA); sw. of Lockeford, *Landolt 8180* (ZT). STANISLAUS CO.: Knights Ferry, *Landolt 6592* (ZT); La Grange, *Landolt* (ZT).

Wolffia borealis occurs at each end of the state in remarkably disjunct populations, including Shasta County (Fall River Mills) and San Diego County (Lake Hodges and San Dieguito River). A third site was recently discovered in Mendocino County by D. Richards (Humboldt State University), who plans to publish a note on it.

California: MENDOCINO CO.: s. of Willits, *Richards 104* (HSU, RSA, SD). SAN DIEGO CO.: Lake Hodges, *Armstrong 1123* (SD); San Dieguito River, *Armstrong 1124, 1167, 1183* (RSA, SD). SHASTA CO.: Fall River Mills, *Mason 14629* (MO, RSA, UC).

These species of *Wolffia* have rather extensive distributions outside the state and are undoubtedly much more abundant than data from collection sites indicate. Fronds and seeds of *Wolffia* and other members of the Lemnaceae may be dispersed over short distances by waterfowl (Jacobs 1947, van der Plas 1971, Wolek 1981). According to Thompson (1896), fronds of *Wolffiella lingulata* (Hegelm.) Hegelm. may have gradually been carried to California from central Mexico by migratory birds. Although survival of vegetative fronds of *Wolffia* for several hours out of water is unlikely due to desiccation, some could possibly survive in clods of mud and debris or under feathers where they are protected from the wind. At 20–21°C and relative humidity 55–60%, a mass of *W. arrhiza* weighing 1.0 g can survive almost 6 hours of desiccation (Godziemba-Czyz 1970). Under similar conditions single individuals of *W. arrhiza* can survive only 20–30 minutes of desiccation (Wolek 1981). Disseminules may also be transported by river currents, flood waters, and possibly by man when lakes are stocked with fish and in the shipment of aquarium cultures. North American species also produce starch-filled, dormant fronds called turions that sink to the bottom and survive cold winters (Landolt 1981).

Wolffia columbiana occurs in the Pacific states from southern California to Oregon and throughout the eastern United States and Ontario, Canada, extending sporadically south in Mexico, El Salvador, Guatemala, Colombia, Venezuela, Uruguay and Argentina

(Daubs 1965; Hitchcock, Cronquist and Ownbey 1969; Landolt and Urbanska-Worytkiewicz 1980). *Wolffia borealis* is essentially a boreal species of the Pacific, midwestern, and eastern United States and southern Canada (Landolt and Urbanska-Worytkiewicz 1980). It is also reported (as *W. punctata*) from eastern Texas, Georgia, and southeastern United States (Thorne 1956, Correll and Correll 1975, Clark 1979). According to Landolt (pers. comm. 10 May 1983), these southern populations may actually be of *W. brasiliensis.*

Wolffia globosa has the most widespread distribution of all, although restricted in North America to the Central Valley of California, San Diego County and to Southern Florida. A recent collection in Pinellas Co. (*Armstrong 1182*) may be the first record of this species in Florida. It also occurs in southern and eastern Africa, Sri Lanka, India, eastern and southeastern Asia, Japan, Indonesia, Malaysia, Philippines, and the Hawaiian Islands (Landolt and Urbanska-Worytkiewicz 1980). Records of *W. arrhiza* in southeast Asia are probably *W. globosa,* a species that may occur in Australia (van der Plas 1971). Landolt (1980a) lists only two species from Australia, *W. angusta* Landolt and *W. australiana* (Benth.) Hartog and Plas. It is possible that some collections from Australia labeled *W. globosa* are actually the closely related *W. angusta.* The occurrence of *W. globosa* in the Central Valley of California is perplexing. According to Landolt (1981) it may not be indigenous to North America. Possibly, like other aquatic "weeds" from Asia, *W. globosa* first became naturalized in rice fields in the Central Valley. Some of these Asian introductions are *Eriocaulon cinereum* R. Br., *Najas graminea* Raff.-Delile, *Scirpus mucronatus* L., *S. tuberosus* Desf., *Eleocharis atropurpurea* (Retz.) Kunth., *Cyperus difformis* L., *Elatine ambigua* Wight, and *Monochoria vaginalis* (Burm. f.) Presl.

Conclusions

Vegetative propagation predominates in the Lemnaceae, and different geographical populations of the same species may differ in general appearance (Landolt 1957). Under 10–20× magnification the California species of *Wolffia* are sufficiently different from each other to be distinguished on the basis of size and shape of their fronds. Brown pigment cells in the epidermis of *W. borealis* are clearly evident in dried specimens. Although soaking dried specimens in water is useful for identification of *Lemna* species, it is inadequate for *Wolffia* because the fronds generally remain flat and deformed. Ideally, it is perhaps best to examine living plants or fronds preserved in FAA or ethanol. Flowers and fruits are probably too infrequently observed to be of much value in identifying species of *Wolffia.* Proterogyny has been reported for most species (den

Hartog and van der Plas 1970) and this also appears to be the case with *W. borealis* in San Diego County (Armstrong 1982).

As in other members of the Lemnaceae, there may be considerable ecophysiological and cytogenetic variation among different species of *Wolffia,* and among different geographical populations of the same species (Landolt 1957, 1981, 1982; Hillman 1961; Landolt and Wildi 1977; Urbanska-Worytkiewicz 1980). Urbanska-Worytkiewicz (1980) reported a tetraploid number of 40 for *W. columbiana* from Oso Flaco Lake, and polyploid numbers of 30 and 60 for populations of *W. globosa* from the San Joaquin Valley. Future cytological and physiological studies may provide a better understanding of the ecological requirements and distribution of *Wolffia* species in California. Additional studies on the distribution of all three species along waterfowl migration routes and the survival of fronds under conditions of desiccation may elucidate the possible role of waterfowl in exozoic dispersal of *Wolffia* species in California.

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